

WUE-ITP-99-023
hep-ph/9909549**POLARIZATION AND SPIN EFFECTS IN NEUTRALINO
PRODUCTION AND DECAY IN SUPERSYMMETRIC MODELS**G. MOORTGAT-PICK ^a, S. HESSELBACH ^b, F. FRANKE ^c, H. FRAAS ^d
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We study polarization and spin correlation effects in the MSSM and in extended supersymmetric models at an e^+e^- linear collider with polarized beams. The production of light neutralinos $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ and the subsequent decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 e^+e^-$ including full spin correlations is compared in three supersymmetric models: MSSM, NMSSM and an E_6 -inspired model with an additional $U(1)'$ gauge group. It is shown that polarization and spin effects can lead to a complete different behavior of these models. Finally, the dependence of the cross section and the decay angular distribution on the gaugino mass parameter M_1 for polarized beams is briefly outlined.

1 Introduction

The production of neutralinos at an e^+e^- linear collider and their subsequent decays offer excellent opportunities to measure the neutralino masses and mixings. Especially beam polarization and spin correlation effects play an important role for determinating precisely the parameters of the underlying supersymmetric model and discriminating between different SUSY models.

In our contribution, we study the production of the light neutralinos $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ with polarized beams and the subsequent leptonic decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 e^+e^-$ in three different SUSY models: the Minimal Supersymmetric Standard Model (MSSM) with and without the GUT relation for the gaugino mass parameters M_1 and M_2 , the Next-to-Minimal Supersymmetric Standard Model (NMSSM) with an additional Higgs singlet superfield and an E_6 inspired model with a new $U(1)'$ gauge boson.

Since the angular distribution of the decay products depend on the neutralino polarization, the spin correlations between production and decay are included. In fact, spin correlations turn out to have a strong influence on the decay angular distribution which forbids simple factorization into a production and a decay factor. For the MSSM the spin effects have been studied in Ref. ¹. These methods are now applied to extended supersymmetric models with a singlino-like lightest neutralino.

The models and the scenarios are described in the following section. Numerical results for neutralino production cross sections, decay angular distributions and forward-backward-asymmetries are presented in Secs. 3 and 4. We conclude this paper with a short survey of the M_1 -dependence of the cross sections and forward-backward asymmetries for polarized beams in the MSSM.

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Model	M_2/GeV	M'/TeV	μ/GeV	x/TeV	λ	κ	$\tan\beta$
MSSM	152	-	316	-	-	-	3
NMSSM	262	-	-	1	0.9	0.0295	3
E_6	270	22.3	-	3	0.15	-	3

Table 1: Parameters of the supersymmetric models. All scenarios lead to neutralino masses $m_{\tilde{\chi}_1^0} = 72 \text{ GeV}$ and $m_{\tilde{\chi}_2^0} = 130 \text{ GeV}$.

2 Scenarios

2.1 MSSM

In the MSSM² we refer to the the DESY/EFCA reference scenario for the Linear Collider³ which is given in Table 1. This scenario implies the GUT relation $M_1/M_2 = 5/3 \tan^2 \theta_W$ and leads to gaugino-like light neutralinos with masses $m_{\tilde{\chi}_1^0} = 72 \text{ GeV}$ and $m_{\tilde{\chi}_2^0} = 130 \text{ GeV}$. For comparison, these mass eigenvalues as well as the selectron masses $m_{\tilde{e}_L} = 197 \text{ GeV}$, $m_{\tilde{e}_R} = 160 \text{ GeV}$ are fixed in all models.

2.2 NMSSM

The NMSSM⁴ is the simplest extension of the MSSM by a Higgs singlet field which enlarges the neutralino sector from four neutralinos in the MSSM to five NMSSM neutralinos. New parameters in the neutralino sector are the singlet vacuum expectation value x and the trilinear couplings λ and κ in the superpotential.⁵ A scenario with a singlino-like lightest neutralino (Table 1) leads to significantly different signatures compared to the MSSM.⁶ In this case the masses and mixings of the neutralinos $\tilde{\chi}_{2,\dots,5}^0$ correspond to $\tilde{\chi}_{1,\dots,4}^0$ of the MSSM with $\mu = \lambda x$.

2.3 E_6 -model

Models with additional U(1) factors in the gauge group are a further extension of the MSSM beyond the NMSSM. We study an E_6 -model with one new gauge boson Z' and an extended Higgs sector with one singlet superfield⁷, which contains six neutralinos.⁸ Assuming $M' = M_1$ for the U(1) gaugino mass parameters the four lighter neutralinos have MSSM-like character. For $M' \gg x$, however, the lightest neutralino can be a nearly pure singlino.⁹ Such a scenario (Table 1) where the spectrum of the lighter neutralinos is similar to the NMSSM will be discussed in the following.

3 Cross sections

Figs. 1–3 show the cross sections for neutralino production for unpolarized beams and for the different polarization configurations. In our scenarios with gaugino- and singlino-like light neutralinos, they mainly depend on the selectron masses and on the following combinations of the $e\tilde{e}\tilde{\chi}_i^0$ -couplings f_i^L and f_i^R of the left- and

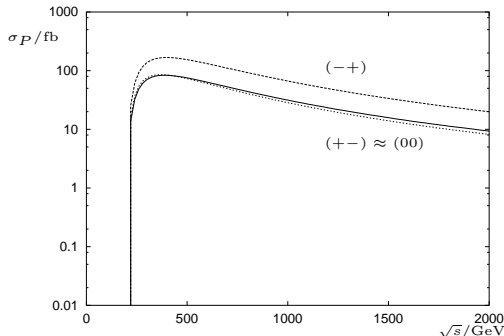


Fig. 1: Cross section $\sigma_P(e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0)$ for unpolarized beams (00) and longitudinal beam polarizations $P_- = -85\%$, $P_+ = +60\%$ $(-+)$ and beam polarizations $P_- = +85\%$, $P_+ = -60\%$ $(+-)$ in the MSSM (Table 1).

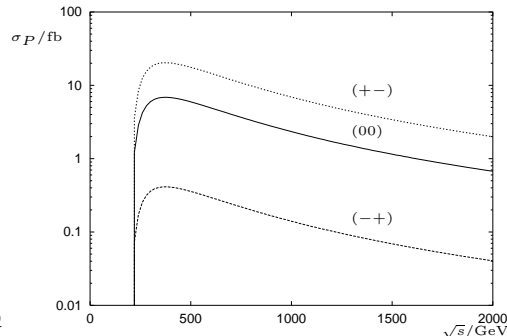


Fig. 2: Cross section $\sigma_P(e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0)$ for unpolarized beams (00) and longitudinal beam polarizations $P_- = -85\%$, $P_+ = +60\%$ $(-+)$ and beam polarizations $P_- = +85\%$, $P_+ = -60\%$ $(+-)$ in the NMSSM (Table 1).

right-handed selectrons: ²

$$\text{MSSM : } f_1^L f_2^L = -0.2, \quad f_1^R f_2^R = -0.12, \quad (1)$$

$$\text{NMSSM : } f_1^L f_2^L = -0.0007, \quad f_1^R f_2^R = 0.06, \quad (2)$$

$$E_6 : f_1^L f_2^L = -0.003, \quad f_1^R f_2^R = -0.03. \quad (3)$$

In the MSSM, the unpolarized $\tilde{\chi}_1^0 \tilde{\chi}_2^0$ cross section reaches its maximum value of ~ 90 fb at about threshold and decreases for CMS-energies of 2 TeV to 10 – 20 fb. Due to the dominating left-handed selectron couplings the beam polarizations $(-+)$ (left handed polarized electrons and right-handed polarized positrons) enhance the cross sections by a factor of about 2.

In the extended models (Figs. 2, 3), the $\tilde{\chi}_1^0 \tilde{\chi}_2^0$ cross sections are generally small ($\sim 1 - 10$ fb) due to the weak couplings of the singlino-like $\tilde{\chi}_1^0$. Nevertheless, even a neutralino with a 99% singlino component can be directly produced at a linear collider with a high luminosity $L = 500 \text{ fb}^{-1}$ which corresponds to the TESLA scheme.¹⁰ Cross sections for the NMSSM and E_6 -model are rather similar with the exception of the Z' peak at $\sqrt{s} = 1264$ GeV. Since the additional gauge boson considerably couples to the singlino-like $\tilde{\chi}_1^0$ this peak is rather distinct for $\tilde{\chi}_1^0 \tilde{\chi}_2^0$ production.

Contrary to the MSSM scenario the cross sections are enhanced for the polarization configuration $(+-)$ by a factor 3 due to the dominating right-handed couplings, while they are strongly suppressed for the opposite beam polarization.

4 Decay angular distributions

Since the spin correlations are strongest near threshold we study the decay angular distributions for the CMS-energy $\sqrt{s} = m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0} + 50$ GeV. For unpolarized beams the angular distribution between the incoming and the decay electron in the MSSM

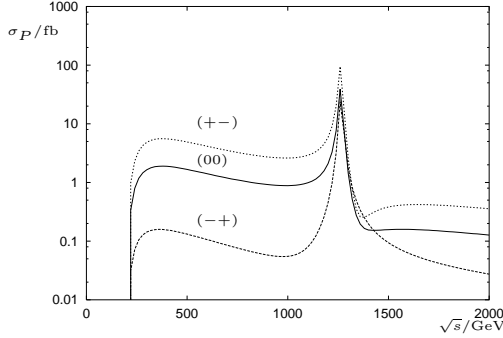


Fig. 3: Cross section $\sigma_P(e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0)$ for unpolarized beams (00) and longitudinal beam polarizations $P_- = -85\%$, $P_+ = +60\%$ $(-+)$ and beam polarizations $P_- = +85\%$, $P_+ = -60\%$ $(+-)$ in the E_6 -model (Table 1).

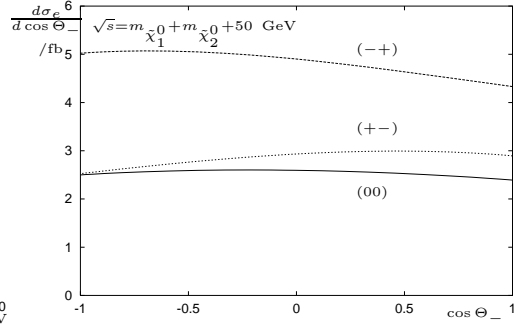


Fig. 4: Decay angular distribution of the decay electron in $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 e^+e^-$ with complete spin correlations between production and decay for beam polarizations (00), $(-+)$ and $(+-)$ in the MSSM (Table 1).

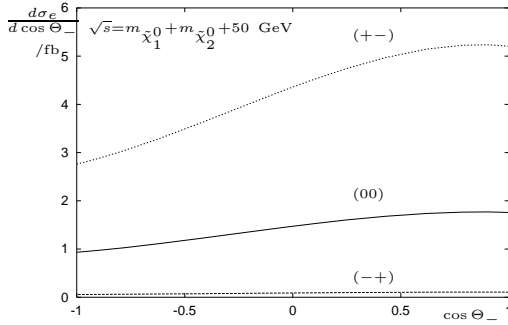


Fig. 5: Decay angular distribution of the decay electron in $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 e^+e^-$ with complete spin correlations between production and decay for beam polarizations (00), $(-+)$ and $(+-)$ in the NMSSM (Table 1).

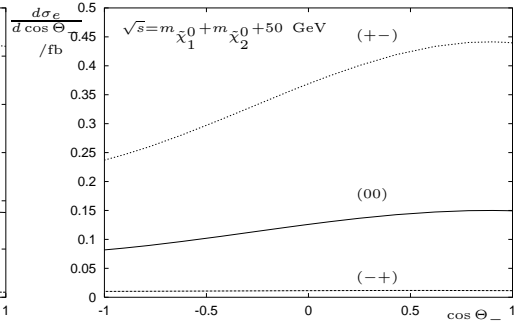


Fig. 6: Decay angular distribution of the decay electron in $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 e^+e^-$ with complete spin correlations between production and decay for beam polarizations (00), $(-+)$ and $(+-)$ in the E_6 -model (Table 1).

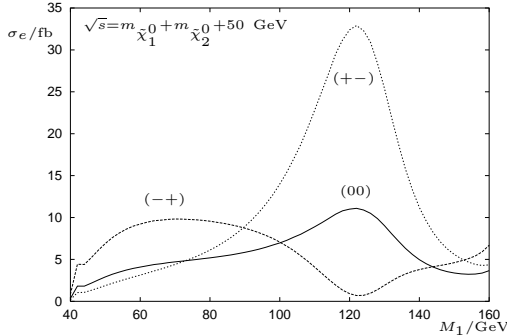


Fig. 7: Cross section $\sigma_e = \sigma_P(e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0) \times BR(\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 e^+ e^-)$ in dependence of the M_1 -parameter for beam polarizations (00), (-+) and (+-) in the MSSM (Table 1).

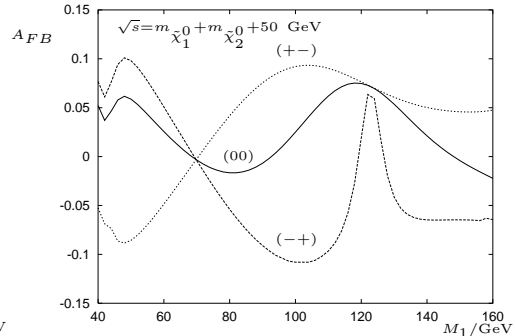


Fig. 8: Forward-backward-asymmetry of lepton decay angular distribution in dependence of the M_1 -parameter for beam polarizations (00), (-+) and (+-) in the MSSM (Table 1).

(Fig. 4) shows a very small forward-backward-asymmetry $A_{FB}^{(00)} \approx -1.2\%$ since the larger coupling of the left-handed selectron is compensated by its bigger mass. With beam polarizations (-+) \tilde{e}_R exchange is heavier suppressed resulting in a more clearly negative $A_{FB}^{(-+)} \approx -4.1\%$ while the opposite polarization configuration leads to a positive $A_{FB}^{(+-)} \approx +3.8\%$ due to the suppressed \tilde{e}_L exchange.

In the NMSSM and E_6 -scenarios with larger right-handed selectron couplings, however, one obtains strong positive decay angular asymmetries (Figs. 5, 6). While the forward-backward-asymmetry of about 17% in the NMSSM only weakly depends on the beam polarizations, the spin correlation effects lead to $A_{FB}^{(00)} \approx A_{FB}^{(+-)} \approx 16\%$ and $A_{FB}^{(-+)} \approx 4\%$ for the E_6 -scenario.

5 M_1 -dependence

Neglecting the GUT-relation between M_1 and M_2 , the changing selectron couplings lead to dramatically different polarization effects which may be used for imposing bounds on M_1 .¹¹ Fig. 7 shows the strong M_1 -dependence of the cross section $\sigma_e = \sigma_P(e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0) \times BR(\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 e^+ e^-)$ for polarized beams in the MSSM. The interplay of left- and right-handed selectron couplings now causes a significant increase of the small forward-backward-asymmetry of Fig. 4; e. g. up to about +5% for unpolarized beams (Fig. 8).

More details on the M_1 -dependence can be found in Ref. ¹². The methods for the determination of the M_1 parameter may analogously applied to extended models with similar results.

6 Conclusion

A high luminosity e^+e^- linear collider is needed for the direct production of a neutralino with a large singlino component in extended supersymmetric models

since the cross sections (beyond a possible Z' peak) are highly suppressed compared to the MSSM. Further, polarization of both beams is an important tool to increase the event rates.

Polarization effects strongly depend on the relation between left- and right-handed electron-selectron-neutralino-couplings and selectron masses. Therefore decay angular distributions and forward-backward-asymmetries may help to distinguish between different supersymmetric models.

In a similar manner polarization effects reflect the dependence of the neutralino couplings and masses on the gaugino mass parameter M_1 and supply additional informations for the determination of the parameters of the underlying supersymmetric model.

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